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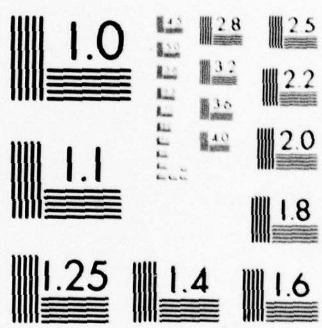

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Four men and four women with comparable maximal aerobic capacities (57 and 51 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively) and equal surface areas and surface area to mass ratios underwent a three hour heat stress test ($T_{db} = 36°C$, $T_{wb} = 30°C$, $\dot{V}O_2 = 1.0\ L \cdot min^{-1}$) before and after a 10 day acclimation to humid heat ($T_{db} = 36°C$, $T_{wb} = 32°C$). Women were tested during both pre- and post-ovulation (pre-OV, post-OV). Prior to acclimation, pre-OV women exhibited the longest tolerance times and lowest rectal temperatures (T_{re}) and heart rates (HR) throughout testing. Men secreted considerably more sweat per unit area than did women in either phase of the cycle, yet they demonstrated shorter tolerance

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PHYSIOLOGICAL RESPONSES OF PHYSICALLY FIT MEN AND WOMEN TO ACCLIMATION TO HUMID HEAT

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Running Head: Heat Responses of Fit Men and Women

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Abstract

Four men and four women with comparable maximal aerobic capacities ~~(57 and 51 ml · kg^{-1} · min^{-1}, respectively)~~ and equal surface areas and surface area to mass ratios underwent a three hour heat stress test ~~(T_{db} = 36°C, T_{wb} = 30°C, $\dot{V}O_2$ = 1.0 L · min^{-1})~~ before and after a 10 day acclimation to humid heat, ~~(T_{db} = 36°C, T_{wb} = 32°C)~~. Women were tested during both pre- and post-ovulation (pre-OV, post-OV). Prior to acclimation, pre-OV women exhibited the longest tolerance times and lowest rectal temperatures (TRE) (T_{re}) and heart rates (HR) throughout testing. Men secreted considerably more sweat per unit area than did women in either phase of the cycle, yet they demonstrated shorter tolerance times and higher body temperatures and HR. During post-OV, women reacted similarly to men, although their sweat rates and HR's were significantly lower. Following acclimation, the TRE T_{re} and HR of the men and women were similar while the discrepancy between the sweat rates was magnified. It was concluded that aerobic capacity is an important factor to be considered when men and women are compared in the heat. When fitness levels are similar, except for sweating, the previously reported sex-related differences in response to heat seem to disappear.

Index terms: Tolerance to heat; sex differences in humid heat exposures; acclimation to humid heat

There has been much controversy in the past concerning apparent physiological differences existing between the sexes when both are exposed to identical heat stress. Women have usually been deemed less able to cope with an acute heat exposure since their sweat rates are substantially lower than those of men (8,12,24) However, in studies in which men and women were compared after acclimation, the conventional indicators of physiological stress (i.e., rectal temperature (T_{re}) and heart rate (HR)) were similar despite the lower rates of sweating in the women (21,24). The emphasis, therefore, appears to have been mainly with the quantity of sweat secreted and not necessarily with the efficiency of the sweating process.

When men and women are compared during exercise in the heat, the work load utilized may compound the effect of any sex-related physiological discrepancy. Higher HR's and core temperatures during an acute heat exposure have been found in women performing the same absolute work load as men (12,24). With their lower maximal aerobic capacities, the women would have been at a distinct disadvantage while working in the heat since it is the relative work load and not the absolute work load which determines both core temperature and heart rate during exercise (18,19). When the work load is adjusted to equal fractions of aerobic capacity for both men and women, the men will usually be working at a higher absolute intensity. Thus, although T_{re} and HR would be the same, the men would secrete sweat at a more rapid rate to dissipate their greater metabolic heat load. It is not known therefore how much of the reported physiological differences between the sexes in their initial response to heat result from differing aerobic capacities.

Another sex difference to be considered is body surface area. Since the rate of heat transfer is a function of surface area, subjects with a larger surface

area would be able to lose heat at a faster rate than subjects with a smaller surface area, provided the metabolically active tissue mass is the same. However, men usually have a greater mass than women and hence have a smaller surface area to mass ratio (A_D/wt). This smaller A_D/wt ratio would prove advantageous in environments in which ambient temperature exceeds skin temperature since less heat will be gained from the environment via radiation and convection (R+C). On the other hand, when skin temperature is above ambient temperature the larger A_D/wt ratio in females would be more of an advantage because of their larger area available for heat loss in relation to the smaller mass for heat production.

The thermoregulatory effect of the hormonal fluctuations which occur throughout the menstrual cycle should not be overlooked when comparing the sexes. It is generally believed that pre-ovulatory women may be superior to women in the post-ovulatory phase when both undergo the same heat stress (3,11). Pre-ovulatory women have been shown to act in a manner similar to men (3), while during post-ovulation, a longer delay in the onset of sweating and hence more heat storage has been found to occur.

In order to diminish the effect of the aforementioned variables which may mask existing sex-related differences in heat tolerance, the following guidelines for comparing the sexes were established: 1) the subjects should be as close as possible in their maximal aerobic capacities; 2) the subjects should be matched on A_D/wt ratios; 3) the test should be conducted under minimal dry heat exchange between the subjects and the environment; 4) the women should be heat-exposed in the pre- and post-ovulatory phases of the menstrual cycle; 5) subjects should be compared before and after acclimation.

METHODS AND PROCEDURES

Four men and four women participated in this study during the winter

months. All subjects were healthy, physically fit and had not been exposed to heat since the preceding summer. After consenting to participate, subjects were administered a preliminary physical examination, including a 12-lead ECG and progressive treadmill exercise test, and declared qualified to participate by a physician.

The physical characteristics of the subjects are shown in Table 1. As is evident, the men and women were fairly well matched on height, weight, surface area, surface area to mass ratio and percentage body fat. The maximal aerobic capacity ($\dot{V}O_2$ max) of the men was 57.1 $ml \cdot kg^{-1} \cdot min^{-1}$ which was significantly higher ($p < 0.05$) than the $\dot{V}O_2$ max of 51.5 $ml \cdot kg^{-1} \cdot min^{-1}$ for the women.

Insert Table 1 about here

Measurements. A thermistor probe inserted 8.0 cm beyond the anal sphincter was used for continuous monitoring of deep body temperature. Ear temperature was measured by means of a tympanic thermocouple (Radiation Systems, Inc.) inserted into the outer ear canal close to the tympanic membrane. Skin temperature was measured with uncovered copper-constantan thermocouples attached to the skin at six sites: forehead, right forearm, right thigh, upper chest, upper back, and abdomen. Mean skin temperature ($\bar{T}_{sk}$) was calculated as the unweighted average of the six sites. Heart rate was measured every 5 min from the ECG recording.

Total body sweat rate (SR) was determined from nude body weight measured every 30 min on a scale accurate to $\pm$ 10 g. Correction was made for water intake. Onset of sweat was determined from ten cm^2 plexiglas capsules affixed to the right upper chest and left lower back (4). Dried air was passed

over the encapsulated skin area. The moisture content of the effluent air was then determined by an EG&G Dew Point Hygrometer. Output from the hygrometer was fed to a Beckman Type RM dynograph for continuous monitoring of the local SR. The first initial burst of sweating above the stable baseline was taken as the onset of thermal sweating. A thermocouple touching the skin under the capsule permitted the determination of local skin temperature at sweat onset.

A two-minute sample of expired air was collected and analyzed for O_2 and CO_2 concentration using a Beckman F-3 oxygen analyzer and an MSA Lira Model 300 infrared analyzer, respectively. The volume of gas was measured with a Parkinson-Cowan dry gas meter and corrected to STPD. The external work component, resulting from the uphill walking, was subtracted from the total heat of metabolism to yield the net rate of metabolic heat production (M).

Rate of heat storage (S) was calculated as $S = (0.9 \ \Delta T_{re} + 0.1 \ \Delta \bar{T}_{sk}) \times 0.97 \times wt$ where: ΔT_{re} and $\Delta \bar{T}_{sk}$ = the change in rectal and skin temperature, respectively; 0.97 = specific heat of the tissues in $W \cdot kg^{-1} \cdot {}^{o}C^{-1} \cdot m^{-2}$; wt = weight of the subject in kg.

Since the room had no radiant heat source, the combined rate of radiative and convective (R+C) heat transfer was calculated from the ambient temperature (T_a) as: $R+C = h(T_a-\bar{T}_{sk})$ where: h = combined dry heat exchange coefficient in $W \cdot m^{-2} \cdot {}^{o}C^{-1}$.

Since the study was conducted under humid ambient conditions there was much dripping of sweat onto the treadmill which prevented the determination of evaporation by conventional means. Therefore, the rate of evaporation (E) was estimated from the heat balance equation: $E = M \pm R \pm C - S$ where: all variables are expressed in $W \cdot m^{-2}$.

<u>Procedures</u>. The men and women were exposed to a heat stress test before heat

acclimation and again after acclimation. In addition, the women were heat-exposed during two phases of the menstrual cycle before as well as after acclimation. The study therefore included one pre-acclimation and one post-acclimation heat stress test for the men, but two pre-acclimation and two post-acclimation tests for the women.

Ovulation (OV) was detected by the rise in the daily oral basal temperature. The heat stress tests were performed within five days of either the initiation of the menstrual flow (pre-OV) or the rise in the early morning temperature (post-OV). Since two weeks usually intervened between these two tests, it was unlikely that acclimation effects influenced the women's responses in the second initial test. After the acclimation period, they underwent additional exposures to heat to prevent the loss of acclimation during the time intervening between the two final heat stress tests. To maintain acclimation, relatively short sessions (50-70 min) were administered every other day. The sequence of the pre- and post-OV tests was randomized for each woman both before and after acclimation.

The conditions for the heat stress tests for the men and women were identical. Subjects walked on a treadmill for three hours at 5.6 km • hr^{-1} up a two percent grade in a chamber maintained at 36°C T_{db} and 30°C T_{wb}. Since there was no forced air movement, the effective wind velocity was that due to the speed of walking (~ 0.5 m • sec^{-1}). During acclimation, subjects walked at the same work load for two hours only. The T_{db} remained at 36°C while the T_{wb} was raised to 32°C.

Each subject reported to the laboratory at the same time every day. Initial nude weight was obtained and the subject then dressed for the session. Clothing consisted of shorts, socks, and tennis shoes. In addition, the women wore a halter top. Initial values of T_{re}, HR, $\bar{T}_{sk}$ and local SR were obtained prior to

beginning the walk. The two-min expired gas sample was collected at 45 min. Skin temperature, T_{re}, T_{ear}, and local SR were monitored continuously during the entire exposure. Heart rate was measured every 5 min. The test was terminated if any of the following occurred: HR greater than 90% of the maximal HR, T_{re} greater than 39.0°C, dizziness, nausea, or dry skin.

Statistical Analysis. A three-factor ANOVA design of sex x acclimation state x time was used to test differences between men and women before and after acclimation. To compare women in either stage of the menstrual cycle, a three-factor design was also utilized with the factors being menstrual phase x acclimation state x time. The Scheffe multiple comparison procedure for post-hoc comparisons was used as a follow-up if significant F-tests were found.

RESULTS

The rate of metabolic heat production while walking at 5.6 km • hr^{-1}, two percent grade was similar for both men and women (Table 1); both worked at approximately 30% $\dot{V}O_2$ max.

Physiological Reactions to Heat Before Acclimation. Prior to acclimation, there was much variation in the subjects' tolerance of the moderate exercise under the humid heat. It appeared that the pre-OV women were the most heat-tolerant since their total time in the heat (143 min) was greater than either the post-OV women or the men (112 min).

Only one male (M-4) reached an objective point of termination when his HR exceeded 90% of his HR_{max} at 90 min. M-1 withdrew at 60 min complaining of lightheadedness, M-3 became dizzy at 120 min and M-2 was experiencing dry skin and a severe headache at 170 min at which time he was withdrawn from the chamber. During both pre- and post-OV, one female (F-1) walked for 180 min without her T_{re} or HR becoming unduly high. The T_{re} of F-2 exceeded 39°C at 150 min during pre-OV and at 120 min during post-OV. F-3 similarly walked

longer while tested during pre-OV (150 min compared to 60 min during post-OV) before her T_{re} exceeded 39°C. During both the pre- and post-OV tests F-4 remained in the chamber until 90 min at which time she voluntarily requested termination due to dizziness.

Since two males and two post-OV females were not able to walk beyond 90 min, comparison of the subjects will be made only to this time period. It can be seen in Figure 1 that the three groups began the heat exposure with similar resting values of HR and T_{re} ($p > 0.05$). With time, core temperatures for males rose to higher levels than those of either the pre-or post-OV females. Significant differences were found between the men and the pre-OV women at 60 and 90 min only ($p < 0.05$). Final T_{re} of the men was 38.60°C while the women reached 38.23°C and 38.40°C in the pre-and post-OV phases, respectively.

Insert Figure 1 about here

The men began the heat exposure with a 1°C lower skin temperature than the women. There was no difference in the initial $\bar{T}_{sk}$ of the women in either of the menstrual phases. Once exercise commenced, the post-OV women exhibited a larger rise in $\bar{T}_{sk}$ throughout the duration of the test, while the men and pre-OV women experienced similar increases. However, none of the differences were significant ($p > 0.05$).

The most obvious difference between the sexes was noticeable in the HR response to 90 min of exercise. The men were consistently 15-20 beats per min (bpm) higher than the women during the 30-, 60- and 90-min measurements, despite no difference in their pre-exposure values. The men continued to show a definite increase in HR throughout the test duration, while the women tended to level off after one hour in the heat. Calculation of the 90-min HR as a

percentage of the maximal HR of each individual, showed the males to be working at 74% HR_{max} with the females at 67% in both phases of the menstrual cycle. This difference was not significant.

Figure 2 presents the SR of the subjects for each 30-min period during the two heat stress tests. In the pre-acclimation test, the mean half-hourly SR of the men was significantly greater ($p < 0.05$) than the SR of the women at 30 and 60 min only. The 90-min SR was similar for all three groups. There was no difference between the SR of the women in either pre- or post-OV although the SR's during post-OV tended to lag behind those of pre-OV.

Insert Figure 2 about here

The mean total hourly SR for the men was 522 $\pm$ 53 $g \cdot m^{-2} \cdot hr^{-1}$, while the women's SR's were 433 $\pm$ 39 and 377 $\pm$ 26 $g \cdot m^{-2} \cdot hr^{-1}$ during pre- and post-OV, respectively. Thus, men sweat 21% more than the pre-OV women and 38% more than the post-OV women. Pre-OV women had a SR 15% higher than that of the post-OV women.

Despite large losses of body water as sweat, it appeared that all subjects were able to maintain a fairly constant body wt throughout the exposure by replacement of sweat loss with tap water. Subjects M-1 and F-4 experienced about a one percent decrease in body wt while in the heat; all other subjects showed no change or a slight increase in body wt with time.

<u>Physiological Reactions to Heat After Ten Days Acclimation.</u> The resting T_{re} was significantly lower in all groups after, as compared to before, acclimation. The post-OV women showed the largest decrease with 0.33°C, followed by the males and pre-OV females with 0.19 and 0.12°C, respectively. Resting HR's of the men and women were not lowered as a result of walking in the heat for ten days.

All subjects easily completed the three-hour walk in the humid heat with no undue physiological strain. Rectal temperature, $\bar{T}_{sk}$, and HR were identical in all three groups until 90 min (Figure 3). After 90 min, the males began to experience a slight drifting upward of T_{re} until the termination of the test, so that the men ended the three-hour exposure with a T_{re} 0.3°C higher than that of the women ($p < 0.05$). Similarly, HR in men increased 15 bpm from 90 to 180 min, producing a 10 bpm difference between the third hour HR of men and women.

Insert Figure 3 about here

The SR of the males increased substantially more than that of the females from the pre- to post-acclimation test as seen in Figure 2. The total SR up to 90 min was 41% higher in the males after acclimation than before, compared to an increase of 11 and 17% for women in pre- and post-OV, respectively. With the exception of the first 30 min, the SR of men was significantly higher at all times after acclimation. Women secreted significantly more sweat after acclimation at 60 min only compared with the pre-acclimation test.

The average total sweat loss of the males for the three-hour exposure was 1944 $g \cdot m^{-2}$ which was significantly higher ($p < 0.05$) than the pre- and post-OV females with 1381 and 1317 $g \cdot m^{-2}$, respectively. The differences between the half-hourly SR's of the men and women were magnified after acclimation, as demonstrated in Figure 2. Whereas in the pre-acclimation heat stress test, the men sweat 21% more than the pre-OV females over the first 90 min, after acclimation, this difference was increased to 53%. Similarly, the males sweat 65% more than the post-OV women compared to 38% more before acclimation.

Onset of Sweating. Table 2 presents the mean values of rectal, ear, and skin

temperatures, as well as the temperature of the skin under the capsule, at the time of sweat onset. Although the absolute delay before sweating onset was longer in post-OV women compared to pre-OV women and men, this difference was not statistically significant. The time delays were not reduced to any appreciable extent in men or women as a result of acclimation. The time between commencement of exercise in the heat and the onset of sweating showed little or no relationship to the T_{ear} (r=0.01), T_{re} (r=0.07), or $\bar{T}_{sk}$ (r=0.5) at which sweating was initiated.

Insert Table 2 about here

After acclimation, there were no significant reductions in the body temperatures at which sweating was initiated, although the mean body temperature of the subjects was found to decrease (See Table 2). Ear temperature showed the largest decline in the post-OV women and men who were found to initiate thermal sweating at a core temperature 0.3°C lower than in the pre-acclimation test. The pre-OV women experienced a mean decrease in T_{ear} of 0.1°C.

There was much variation in the extent each subject decreased the T_{ear} for sweat onset. Subject F-4 demonstrated no difference in T_{ear} at sweat onset either in pre- or post-OV, while F-3 was found to have a T_{ear} 0.7°C lower after acclimation during the post-OV test. All males exhibited a slight reduction in T_{ear} at sweat onset, with M-4 showing the largest decline. It should be noted that both subjects who demonstrated the largest decrease in T_{ear} at sweat onset began the pre-acclimation exposure with the highest core temperature — M-4 with a T_{re} of 37.79°C and F-3 with a T_{re} of 38.09°C. They also experienced the largest decrease in resting core temperature as a result of acclimation.

DISCUSSION

One of the major findings in this study was that before acclimation the women, particularly when tested during pre-OV, exhibited the least physiological strain as judged by rectal temperature, heart rate and total time in the heat. This lower strain was evident despite the significantly lower SR's in the women. After acclimation, the difference in SR between men and women was magnified due to the large increase in sweat production by the men and the relative lack of augmentation in sweating for the women. The large increase in SR for the males with acclimation did not confer any additional thermoregulatory advantage however, as core temperatures and heart rates were similar in the men and women. In fact, since both the resting and the 90-min T_{re} were similar for men and women after acclimation, the women were able to dissipate the metabolic heat at the same rate as that of men with less sweat produced. In other words, per volume of sweat secreted, it would be expected that the women would attain a lower body temperature than that of the men. It was in this context that women have been referred to as more efficient regulators of body temperature (5,21,24).

Since in the high humidity environment of this study the rate of evaporation could not be appreciably increased due to the high ambient vapor pressure, any increase in SR beyond the maximum evaporative capacity of the environment would result in increased dripping of the unevaporated sweat. Indeed, Figure 4 reveals that the percentage of sweat produced but not evaporated over the first 90 min of exposure increased from 96 to 152% in the males as an outcome of acclimation. Such large increases in unevaporated sweat were not evident in the women. Prior to acclimation, 58% and 36% of the sweat was not evaporated by the pre- and post-OV women, respectively. Following acclimation, women in both phases of the menstrual cycle showed a similar increase in

the unevaporated sweat of about 12% which corresponded to their increase in total SR resulting from acclimation.

Insert Figure 4 about here

The fact that the women did not significantly increase their SR with repeated exposures to humid heat agrees with observations by other investigators. Weinman et al. (21) found that females repeatedly exposed to humid heat demonstrated no increase in SR while the men experienced a 41% increase in sweat output from Day 1 to Day 10. Wyndham et al. (24), however, reported a 36% increase in the SR of women acclimated for 10 days to humid heat compared to the 50% increase found for men. One of the differences between these two studies was in the initial physical fitness of the subjects. Weinman et al. tested relatively fit women while Wyndham's group used sedentary females. It may be that the ability of women to increase their SR as a result of acclimation to humid heat is a function of the initial fitness level of the individual. Sedentary women may increase their SR more than active women when repeatedly exposed to humid heat. Our results support the findings of Weinman, et at (21) in that the fit women did not substantially increase their SR with acclimation. Men, on the other hand, may experience an augmentation of sweating regardless of training state since when men were first trained and then acclimated to humid heat, a 30% increase in SR was evident (13).

Inasmuch as women can perform the same amount of work as men with less loss of body fluids, they may have a physiological advantage in the humid heat. Since blood is diverted from splanchnic vessels during heat exposure (17) and absorption from the GI tract thus reduced, fluid lost as sweat may not be completely replaced by water ingestion. The decrease in body fluid would be

reflected in the vascular compartment by a reduction in plasma volume. As the plasma volume is diminished, venous return will be reduced and stroke volume would decrease thereby producing a reciprocal increase in HR. Indeed, prior to acclimation, the men in this study demonstrated HR's 15-20 bpm higher than the women's despite the similarity of the exercise-heat routine. After acclimation, when the fluid compartmental shifts are accomplished more readily and the fluid gained is retained for a longer duration (20), the men demonstrated comparable HR's to the women's. However, after 90 min, their HR began to rise steadily throughout the duration of the exposure so that the men terminated the three-hour test with a HR which was 10 bpm higher than the women's. This again may have been the result of large fluid losses as sweat during the exposure which could not be adequately replaced through ad lib water ingestion.

The results of this investigation demonstrated that the latency period before onset of thermal sweating did not change with repeated exposure to humid heat (Table 2). In addition, the core temperature at sweat onset was not lowered significantly following acclimation. Sweat onset at a lower T_{re} and T_{ear} after acclimation may have merely been a reflection of the reduction in the resting core temperature as a result of acclimation and not actually a change in the threshold for thermal sweating. This is supported by the findings of Subjects F-3 during post-OV and M-4, both of whom exhibited the largest drop in T_{ear} at sweat onset while also showing the greatest decrease in their resting core temperatures following acclimation.

The slight change in core temperature at sweat onset noted in this study may have been a consequence of the fitness of the subjects. It has been reported that sweating begins at lower core temperatures in trained, as opposed to untrained, individuals (7,10).

It is also possible that a change in the latency period and/or core

temperature at sweat onset may have been masked by the individual variation among the subjects. With only four subjects in each group, statistical significance could be difficult to demonstrate.

Role of Fitness in Response to Heat. One rationale behind choosing nonsedentary subjects for this study was to control for any training effects resulting from the daily walks in the heat and thus to separate the effects of progressively increasing fitness from the responses of repeated exposure to heat. Fit individuals would be expected to react with less physiological distress than untrained subjects when exposed to acute heat stress (6,7,9,10,16). This favorable reaction is thought to be related to the more stable cardiovascular system (i.e., a higher stroke volume and lower HR at any given oxygen consumption) and the enhanced sweating for a given change in body temperature which occurs as a consequence of training (7,9,14).

Although the aerobic capacities of the subjects in this study were similar, there was much variation in the tolerance times of the subjects during the initial exposure to heat. The tolerance of individuals to heat, therefore, is probably not simply a consequence of absolute values of aerobic capacity. For example, in a study comparing long distance runners with trained men having the same $\dot{V}O_2$ max, the runners maintained lower HR's and T_{re}'s while performing the same work load in the heat (10). The discrepancy was thought to result from the extensive training of the runners at high rates of energy expenditure for one to two hours per day for several years compared to the short duration of the training program involved in their study. None of the subjects in the present study, however, were involved in any extensive training program other than their routine of jogging, cycling, racquetball, etc.

In general, it appeared that before acclimation, the women, particularly when tested during pre-OV, were more heat-tolerant than the men despite the

similarity of the combined metabolic and external heat stress (Fig 1). It may have been that despite having similar maximal aerobic capacities, the women were relatively more fit than the men. The women with their mean $\dot{V}O_2$ max of 51 $ml \cdot kg^{-1} \cdot min^{-1}$ could be regarded as having a high fitness level while the men appeared to be on the borderline between good and high levels (1). Since the $\dot{V}O_2$ max of women is some 15% lower than men (2), it follows that when men and women of similar $\dot{V}O_2$ max are compared, the latter would be 15% more fit. The relatively more fit women would have a physiological advantage during exercise in the heat due to a more stable cardiovascular system which could maintain adequate transfer of heat to the periphery while delivering sufficient quantities of oxygen to the working muscle. The lower HR of the women during the initial heat stress test (Figure 1) suggests this to be a strong possibility.

Although the greater tolerance of the women during the initial heat exposure has been attributed to a relatively greater fitness level, it should be noted that the men in this study had a significantly higher $\dot{V}O_2$ max than the women. In addition, there was no difference in the $\dot{V}O_2$ max of the men and women when related to lean body mass (64.7 and 64.3 $ml \cdot kg^{-1} \cdot min^{-1}$ respectively). Paolone, et al. (15) recently indicated that fit women may react more favorably to acute heat stress than comparably fit men. Men were found to have less effective evaporative cooling, as measured by reductions in Δ Evaporation/ $\Delta \dot{T}_{re}$ from neutral to warm environments. Additionally, the men increased their $\dot{V}O_2$ in the heat over neutral conditions relatively more than the women, while the women had a greater increase in HR. The authors suggested that the women responded to heat with a greater component of cardiovascular regulation. This increased reliance on vasomotor adjustments was apparently less physiologically costly than increased dependence on evaporation since the women did not demonstrate such large increases in metabolic heat production as did the men.

Effect of Menstrual Phase. There were no significant differences attributable to menstrual phase in any of the measured parameters. However, core temperature and HR's tended to be slightly higher and SR's slightly lower during post-OV in the initial heat stress test. The higher T_{re} at 90 min could be explained by the higher resting core temperature during post-OV (Fig 1). The apparent higher HR evident during post-OV may be explained by the lower plasma volume found after ovulation (22,23). A lower plasma volume would necessitate a higher HR to maintain an adequate cardiac output in the face of the diminished stroke volume.

Conclusions. In conclusion, it appears that previously reported sex-related differences in tolerance to heat may have been a function of the initial physical fitness of the individual. When fit women with comparable A_D/wt ratios as fit men were exposed to an acute humid heat stress, the women maintained similar core temperatures and lower HR's than men with less loss of body fluids as sweat. Since the ambient temperature of the experimental environment was very close to $\bar{T}_{sk}$, exchanges by R+C were negligible. Therefore, for the same required evaporation, the men secreted considerably more wasteful sweat. Successive exposures to the humid heat reduced the HR and T_{re} in both men and women but did not affect as substantial an increase in the SR of women as was evident in men. Before acclimation, menstrual phase did not appear to significantly affect HR responses in the women. Rectal temperature, however, was slightly higher, SR lower and tolerance time less after ovulation as compared to before. Acclimation served to eliminate all the physiological differences noted in the initial heat stress test between men and women and between menstrual phase.

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TABLE 1. Anthropometric measurements, surface area (A_D), surface area to weight ratios (A_D/Wt), maximal oxygen consumptions ($\dot{V}O_2$ max) and oxygen consumption during exercise for all subjects.

Subject	Age Yr	Ht cm	Wt kg	A_D m^2	A_D/Wt $cm^2 \cdot kg^{-1}$	$\dot{V}O_2$ max $ml \cdot kg^{-1} \cdot min^{-1}$	$\dot{V}O_2$ max $ml \cdot kgLBM^{-1} \cdot min^{-1}$	Exercise Metabolism $L \cdot min^{-1}$	Exercise Metabolism $ml \cdot kg^{-1} \cdot min^{-1}$	% Fat*
Males										
M-1	22	174.3	68.6	1.83	26.68	56.6	63.0	1.14	16.6	10.1
M-2	28	179.3	75.8	1.95	25.32	59.2	67.4	1.25	16.5	12.1
M-3	27	175.1	64.5	1.79	27.75	56.6	63.0	1.15	17.8	10.1
M-4	17	168.5	71.4	1.81	25.35	55.8	65.6	1.25	17.5	14.9
Mean	24.0	174.3	70.1	1.85	26.28	57.1	64.7	1.20	17.1	11.8
±SD	4.2	4.5	4.8	0.07	1.16	1.5	2.2	0.06	0.6	2.3
Females										
F-1	25	171.5	60.9	1.72	28.24	49.7	65.9	1.01	16.1	24.6
F-2	25	175.8	62.7	1.77	27.43	50.1	64.4	1.11	17.1	22.2
F-3	23	183.0	70.7	1.92	27.16	49.4	63.7	1.23	17.3	22.4
F-4	21	171.6	60.7	1.71	28.17	56.7	63.1	1.06	17.0	10.2
Mean	23.5	175.5	63.8	1.78	27.75	51.5	64.3	1.10	16.9	19.9
±SD	1.9	5.4	4.7	0.10	0.54	3.5	1.2	0.09	0.1	6.5
Significance: Male vs Female	NS	NS	NS	NS	NS	$p < 0.05$	NS	NS	NS	NS

*As determined by body density from underwater weighing.

TABLE 2. Means (± S.E.) of ear temperature (T_{ear}), rectal temperature (T_{re}), mean skin temperature ($\bar{T}_{sk}$), and local skin temperature (T_{lsk}) at the time of sweat onset before (pre-) and after (post-) acclimation.

Subject	Time (min) Pre	Time (min) Post	Time (min) Δ	T_{ear} (°C) Pre	T_{ear} (°C) Post	T_{ear} (°C) Δ	T_{re} (°C) Pre	T_{re} (°C) Post	T_{re} (°C) Δ	$\bar{T}_{sk}$ (°C) Pre	$\bar{T}_{sk}$ (°C) Post	$\bar{T}_{sk}$ (°C) Δ	T_{lsk} (°C) Pre	T_{lsk} (°C) Post	T_{lsk} (°C) Δ
Pre-OV*	4.7	5.0	+0.3	37.1	37.0	-0.1	37.16	36.97	-0.19	34.7	34.3	-0.4	34.5	33.9	-0.6
	0.7	1.3		0.3	0.1		0.30	0.2		0.3	0.2		0.4	0.5	
Post-OV	7.0	6.4	-0.6	37.3	37.0	-0.3	37.52	37.16	-.36	34.7	34.3	-0.4	34.8	33.8	-1.0
	1.2	3.4		0.2	0.1		0.21	0.10		0.2	+0.4		0.6	0.8	
Males	3.3	1.7	-1.6	37.1	36.8	-0.3	37.35	37.11	-0.14	34.1	34.3	+0.2	32.8	33.0	+0.2
	1.1	0.9	0.2	0.1			0.17	0.14		0.3	0.1		0.7	0.7	

*Mean does not include the data of Subject F-2.

Figure Legends

Fig 1. Time course of rectal temperature (T_{re}), mean skin temperature ($\bar{T}_{sk}$) and heart rate (HR) for men and women during the pre-acclimation heat stress test.

Fig 2. Comparison of the half hourly sweating rates (SR) for men and women before and after acclimation. For the pre-acclimation test, the 1.5 and 2-hour value does not include the data for M-4 or for F-3 during post-OV. The 2-hour value also does not include the data for F-4 during both pre- and post-OV. The 1-, 1.5- and 2-hour values for the post-acclimation test were significantly higher than the pre-acclimation SR's for the men. Both pre- and post-OV women had significantly greater SR's after acclimation at 1.0 hour only. During pre-acclimation, the 0.5- and 1.0-hour SR was higher for men than women, while after acclimation, from 0.5 to 2.0 hour, man had significantly greater SR's ($p < 0.05$).

Fig 3. Time course of rectal temperature (T_{re}), mean skin temperature ($\bar{T}_{sk}$) and heart rate (HR) for men and women during the post-acclimation heat stress test.

Fig 4. Comparisons of mean sweat rate, evaporation rate, and rate of unevaporated sweat production for men and women before and after acclimation.

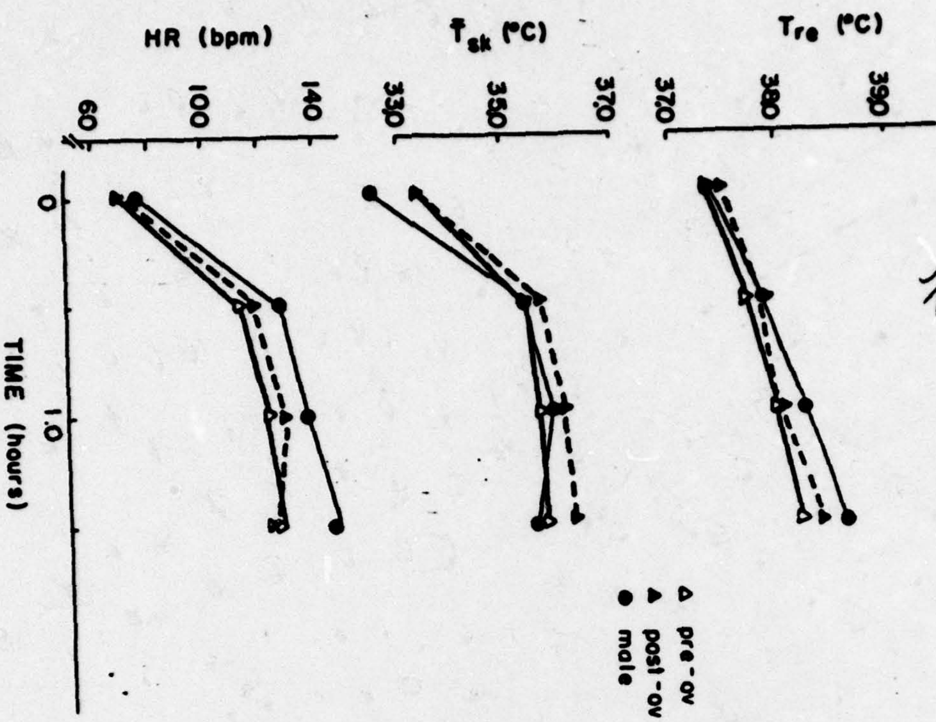
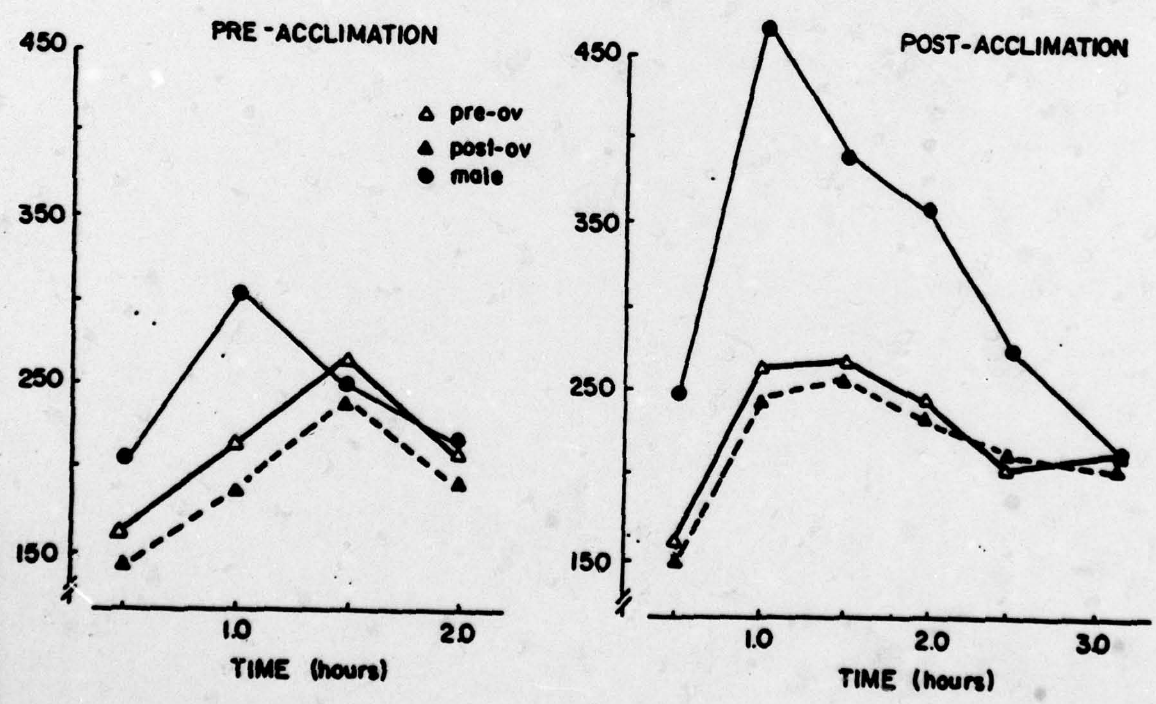


Figure 1

Figure 2



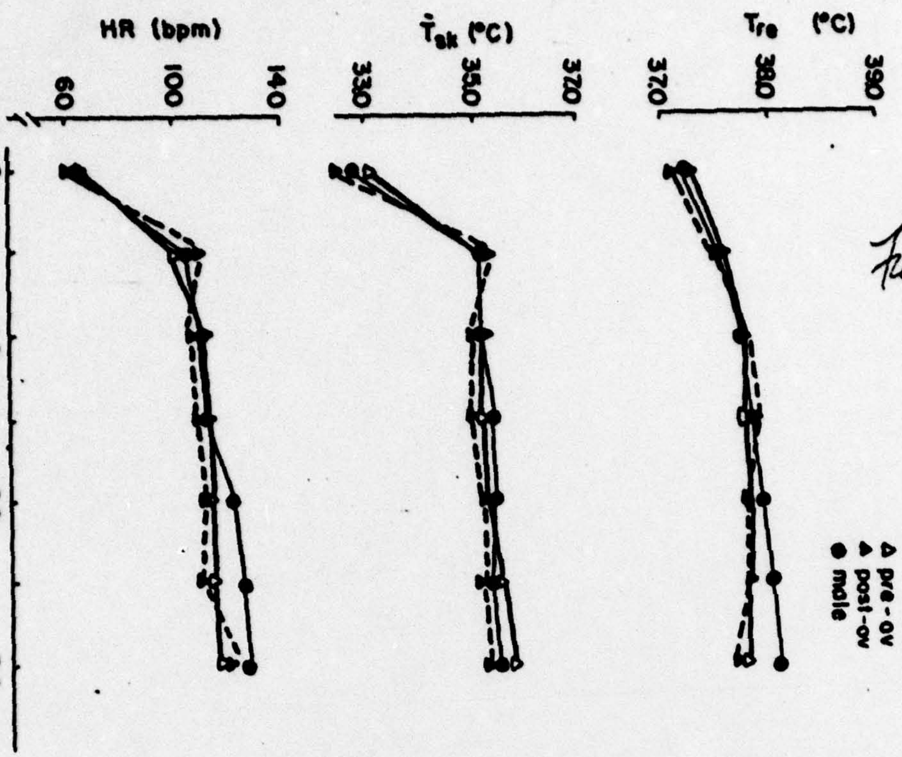


Figure 3

Figure 4